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UNITED STATES LETTERS PATENT

FOR

DRILLING ASSEMBLY WITH A STEERING DEVICE FOR COILED-TUBING OPERATIONS

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TITLE: DRILLING ASSEMBLY WITH A STEERING DEVICE FOR COILED-TUBING OPERATIONS

CROSS-REFERENCE TO RELATED APPLICATION

This application takes priority from United States Patent Application Serial No. 60/036,572, filed on January 29, 1997.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to drill strings for drilling boreholes for the production of hydrocarbons and more particularly to a drilling assembly which utilizes a downhole controllable steering device for relatively accurate drilling of short-radius to medium-radius boreholes. The drilling assembly of the present invention is particularly useful with coiled-tubing operations.

2. Description of the Related Art

To obtain hydrocarbons such as oil and gas, boreholes or wellbores are drilled by rotating a drill bit attached to a drill string end. A large proportion of

the current drilling activity involves directional drilling, i.e., drilling deviated and horizontal boreholes, to increase the hydrocarbon production and/or to withdraw additional hydrocarbons from the earth's formations. More recently, demand for drilling short to medium radius wellbores has been increasing. The term "short radius wellbores" generally means wellbores with radii between 12 and 30 meters, while the term "medium radius wellbores" generally means wellbores with radii between 30 and 300 meters.

Modern directional drilling systems generally employ a drilling assembly that includes a drill bit at its bottom end, which is rotated by a drill motor (commonly referred to as the "mud motor") in the drilling assembly. The drilling assembly is conveyed into the wellbore by a coiled tubing. A fluid ("mud") under pressure is injected into the tubing which rotates the drilling motor and thus the drill bit. The state-of-the-art coiled-tubing drill conveyed drilling assemblies usually contain a drilling motor with a fixed bend and an orienting tool to rotate the high side of the drilling motor downhole in the correct direction. The currently available coiled-tubing drilling assemblies (systems) with such orienting tools are typically more than sixteen (16) meters long. Tools of such length are difficult to handle and difficult to trip into and out of the wellbore. Furthermore, such tools require long risers at the surface. Such orienting tools require relatively high power to operate due to the high torque of the drilling motor and the friction relating to the orienting tool.

To drill a short radius or medium radius wellbore it is highly desirable to be able to drill such wellbores with relative precision along desired or predetermined wellbore paths ("wellbore profiles"), and to alter the drilling direction downhole without the need to retrieve the drilling assembly to the surface. Drilling assemblies for use with coiled tubing to drill short-radius wellbores in the manner described above need a dedicated steering device, preferably near the drill bit, for steering and controlling the drill bit while drilling the wellbore. The device needs to be operable during drilling of the wellbore to cause the drill bit to alter the drilling direction.

The present invention provides drilling assemblies that address the above-noted needs. In one embodiment, the drilling assembly includes a steering device in a bearing assembly which is immediately above the drill bit. The steering device may be operated to exert radial force in any one of several directions to articulate the drill bit along a desired drilling direction. The steering assembly may be disposed at other locations in the drilling assembly for drilling medium radius wellbores. Devices and/or sensors are provided in the drilling assembly to continuously determine the drilling assembly inclination, azimuth and direction. Other measurement-while-drilling ("MWD") devices or sensors may be utilized in the drilling assembly, as is known in the drilling industry.

SUMMARY OF THE INVENTION

The present invention provides a drilling assembly for drilling deviated wellbores. The drilling assembly contains a drill bit at the lower end of the drilling assembly. A motor provides the rotary power to the drill bit. A bearing assembly disposed between the motor and the drill bit provides lateral and axial support to the drill shaft connected to the drill bit. A steering device integrated into the drilling motor, preferably in the bearing assembly provides direction control during the drilling of the wellbores. The steering device contains a plurality of ribs disposed at an outer surface of the bearing housing. Each rib is adapted to move between a normal position or collapsed position in the housing and a radially extended position. Each rib exerts force on the wellbore interior when in the extended position. Power units to independently control the rib actions are disposed in the bearing assembly. An electric control unit or circuit controls the operation of the power units in response to certain sensors disposed in drilling assembly. Sensors to determine the amount of the force applied by each of the ribs on the wellbore are provided in the bearing section. The electric control circuit may be placed at a suitable location above the drilling motor or in the rotating section of the drilling motor.

For drilling short radius wellbores, a knuckle joint or other suitable device may be disposed uphole of the steering d vic to provide a desired b nd in the

drilling assembly above the steering device. Electrical conductors are run from a power source above the motor to the various devices and sensors in the drilling assembly.

During drilling of a wellbore, the ribs start in their normal or collapsed positions near the housing. To alter the drilling direction, one or more ribs are activated, i.e., extended outwardly with a desired amount of force on each such rib. The amount of force on each rib is independently set and controlled. The rib force produces a radial force on the drill bit causing the drill bit to alter the drilling direction.

Examples of the more important features of the invention thus have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

For detailed understanding of the present invention, references should be made to the following d tailed d scription of the preferred embodiment, taken

in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:

Figures 1A-1B show a cross-sectional view of a portion of the drilling assembly with the steering device and the control device disposed in the bearing assembly of the drilling assembly.

Figure 1C shows a rib of the steering device of in **Figure 1A** in an extended position.

Figure 2 is a schematic view of an alternative embodiment of a drilling assembly with steering members in the bearing assembly of the mud motor and the power and control devices for operating the steering members disposed above the mud motor.

Figure 3 is a schematic view of an alternative embodiment of a drilling assembly with steering members and the power and control devices for operating the steering members disposed above the mud motor.

Figure 4 is a schematic view of a configuration of the steering members disposed around a non-rotating housing for use in the steering devices of **Figures 1-4.**

Figure 5 is a schematic view of an alternative configuration of the steering members disposed around a non-rotating housing for use in the steering devices of Figures 1-4.

Figure 6 is a schematic drawing of an embodiment of the drilling assembly according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In general, the present invention provides a drilling assembly for use with coiled tubings to drill wellbores. The drilling assembly includes a drilling motor having a power section and a bearing assembly that provides radial and axial support to the drill bit. A steering device integrated into the bearing assembly provides directional control in response to one or more downhole measured parameters. The steering device included a plurality of independently controlled force application members, which are preferably controlled by a control unit or processor in response to one or more downhole measured parameters and predetermined directional models provided to the control unit.

Figures 1A-1B show a schematic diagram of a steering device 30 integrated into a bearing assembly 20 of a drilling motor 10. The drilling motor 10 forms a part of th drilling assembly 100 (Figure 2). The drilling motor 10

contains a power section 12 and the bearing assembly 20. The power section 12 includes a rotor 14 that rotates in a stator 16 when a fluid 52 under pressure passes through a series of openings 17 between the rotor 14 and the stator 16. The fluid 52 may be a drilling fluid or "mud" commonly used for drilling wellbores or it may be a gas or a liquid and gas mixture. The rotor 14 is coupled to a rotatable shaft 18 for transferring rotary power generated by the drilling motor 10 to the drill bit 50.

The bearing assembly 20 has an outer housing 22 and a through passage 24. A drive shaft 28 disposed in the housing 22 is coupled to the rotor 14 via the rotatable shaft 18. The drive shaft 28 is connected to the drill bit 50 at its lower or downhole end 51. During drilling of the wellbores, drilling fluid 52 causes the rotor 14 to rotate, which rotates the shaft 18, which in turn rotates the drive shaft 28 and hence the drill bit 50.

The bearing assembly 20 contains within its housing 22 suitable radial bearings 56a that provide lateral or radial support to the drive shaft 28 and the drill bit 12, and suitable thrust bearings 56b to provide axial (longitudinal or along wellbore) support to the drill bit 12. The drive shaft 28 is coupled to the shaft 18 by a suitable coupling 44. The shaft 18 is a flexible shaft to account for the eccentric rotation of the rotor. Any suitable coupling arrangement may be utilized to transfer rotational power from the rotor 14 to the driv shaft 28.

During the drilling of the wellbores, the drilling fluid 52 leaving the power section 14 enters the through passage 24 of the drive shaft 28 at ports or openings 46 and discharges at the drill bit bottom 53. Various types of bearing assemblies are known in the art and are thus not described in greater detail here.

In the preferred embodiment of Figures 1A-1B, a steering device, generally represented by numeral 30 is integrated into the housing 22 of the bearing assembly 20. The steering device 30 includes a number of force application members 32. Each force application member is preferably placed in a reduced diameter section 34 of the bearing assembly housing 22. The force application members may be ribs or pads. For the purpose of this invention, the force application members are generally referred herein as the ribs. Three ribs 32, equispaced around or in the outer surface of the housing 22, have been found to be adequate for properly steering the drill bit 50 during drilling operations. Each rib 32 is adapted to be extended radially outward from the housing 22. Figure 1C shows a rib 32 in its normal position 32a (also referred to as the "retracted" or "collapsed" position) and in fully extended position 32b relative to the wellbore inner wall 38.

The operation of each steering rib 32 is independently controlled by a separate piston pump 40. For short radius drilling assemblies, each such pump

40 is preferably an axial piston pump 40 disposed in the bearing assembly housing 22. In one embodiment, the piston pumps 40 are hydraulically operated by the drill shaft 28 utilizing the drilling fluid 52 flowing through the bearing assembly 20. A control valve 33 is disposed between each piston pump 40 and its associated steering rib 32 to control the flow of the hydraulic fluid from such piston pump 40 to its associated steering rib 32. Each control valve 33 is controlled by an associated valve actuator 37, which may be a solenoid, magnetostrictive device, electric motor, piezoelectric device or any other suitable device. To supply the hydraulic power or pressure to a particular steering rib 32, the valve actuator 37 is activated to provide hydraulic power to the rib 32. If the valve actuator 37 is deactivated, the check valve is blocked, and the piston pump 40 cannot create pressure in the rib 32. During drilling, all piston pumps 40 are operated continuously by the drive shaft 28. In one method, the duty cycle of the valve actuator 37 is controlled by processor or control circuit 80 disposed at a suitable place in the drilling assembly 100. **Figure 1A** shows the control circuit 80 placed in the rotor 14 to conserve space. The control circuit may be placed at any other location, including at a location above the power section 10. Instead of using the hydraulic power to operate the pumps 40, each pump 40 may be operated by electric motors suitably disposed in the bearing assembly 20.

Still referring to **Figures 1A-1B**, it is known that the drilling direction can

be controlled by applying a force on the drill bit 50 that deviates from the axis of the borehole tangent line. This can be explained by use of a force parallelogram depicted in Figure 1A. The borehole tangent line is the direction in which the normal force (or pressure) is applied on the drill bit 50 due to the weight on bit, as shown by the arrow WOB 57. The force vector that deviates from this tangent line is created by a side force applied to the drill bit 50 by the steering device 30. If a side force such as that shown by arrow 59 (Rib Force) is applied to the drilling assembly 100, it creates a force 54 on the drill bit 50 (Bit Force). The resulting force vector 55 then lies between the weight on bit force line (Bit Force) depending upon the amount of the applied Rib Force.

In the present invention, each rib 32 can be independently moved between its normal or collapsed position 32a and an extended position 32b. The required side force on the drilling assembly is created by activating one or more of the ribs 32. The amount of force on each rib 32 can be controlled by controlling the pressure on the rib 32. The pressure on each rib 32 is preferably controlled by proportional hydraulics or by switching to the maximum pressure (force) with a controlled duty cycle. The duty cycle is controlled by controlling the operation of the valve actuator 37 by any known method.

The use of axial piston pumps 40 enables disposing such pumps 40 in th bearing assembly and relatively close to th ribs 30. This configuration can

reduce the overall length of the drilling assembly. Placing the ribs 32 in the housing 22 of the bearing assembly 20 aids in drilling relatively shorter radius boreholes. The above-described arrangement of the steering device 30 and the ability to independently control the pressure on each rib 32 enables steering the drill bit 12 in any direction and further enables drilling the borehole with a controlled build-out rate (deviation angle). Preferably a separate sensor 39 is provided in the bearing assembly 20 to determine the amount of force applied by each rib 32 to the borehole interior 38. The sensor 33 may be a pressure sensor, a position measuring sensor or a displacement sensor. The processor 80 processes the signals from the sensor 39 and in response thereto and stored information or models controls the operation of each rib 32 and thus precisely controls the drilling direction.

To achieve higher build-up rates ("BUR"), such as rates of more than 60°/100 feet, a knuckle joint 60 may be disposed between the motor power section 14 and the steering devices 30. The knuckle joint 60 is coupled to the bearing assembly 20 at the coupling 44 and to the shaft 28 with a coupling joint 45. The knuckle joint 60 can be set at one or more bent positions 62 to provide a desired bend angle between the bearing assembly 20 and the motor power section 14. The use of knuckle joints 60 is known in the art and thus is not described in detail herein. Any other suitable device for creating the desired bend in the drilling assembly 100 may be utilized for the purpos of this

invention.

Electric conductors 65 are run from an upper end 11 of drilling motor 10 to the bearing assembly 20 for providing required electric power to the valve actuators 33 and other devices and sensors in the drilling motor 10 and to transit data and signals between the drilling motor 10 and other devices in the system. The rotor 14 and the shaft 28 may be hollow to run conductors 65 therethrough. Appropriate feed-through connectors or couplings, such as coupling 63, are utilized, where necessary, to run the electric conductors 65 though the drilling motor 10. An electric slip ring device 70 in the bearing assembly 20 and a swivel (not shown) at the top of the power section 12 is preferably utilized to pass the conductors 65 to the non-rotating parts in the bearing assembly 20. Electric swivel and slip rings may be replaced by an inductive transmission device. The devices and sensors such as pressure sensors, temperature sensors, sensors to provide axial and radial displacement of the drill shaft 28 are preferably included in the drilling motor 10 to provide data about selected parameters during drilling of the boreholes.

Figure 2 is a schematic view of an alternative embodiment of a drilling assembly 100 with steering members 30 in the bearing assembly 20 of the mud motor 10 and the power and control devices 90 for operating the steering members 30 disposed above th power section 12 of the mud motor 10. In

this configuration the rotor 14 is coupled to the drill shaft 28 by a suitable coupling or flexible shaft 19. A common housing 92 with or without connection joints 93 may be used to house the stator 16, coupling 19 and the bearing assembly 20. A separate fluid line 91 is run from a source of hydraulic power in section 90 to each of the individual force application members 30 through the housing 92. The section 90 contains the pumps and the control valves and the required control circuits to independently control the operation of each of the ribs 30. This configuration is simpler than the configuration that contains the power and/or control devices in the mud motor 10, more reliable as it does not require using mechanical and electrical connections inside the bearing housing 22. It also enables building reduced overall length mud motors 10 compared to the configuration shown in **Figure 1**. The configuration of **Figure 2** allows drilling of the wellbores with a higher build up rate compared due the proximity of the ribs 30 near the drill bit 50 and the shorter length of the drilling motor 10. A stabilizer 83 is provided at a suitable location uphole of the ribs 30 to provide lateral stability to the drilling assembly 100. Alternatively, a second set of ribs 30 may be incorporated into the drilling assembly as described below.

Figure 3 is a schematic view of drilling assembly configuration wherein the ribs 30 are placed above the mud motor 10 and the power unit and the control devices to control the operation of the ribs is disposed in a suitable

section above the mud motor 10. A hydraulic line 93 provides the fluid to the ribs 30. The operation of the steering devices shown in Figur s 2 and Figure 3 are similar to the operation of the embodiment of Figures 1A-1C. In yet another configuration, the ribs 30 may be placed in the bearing assembly 20 as shown in Figure 3 and also above the motor 10 as shown in Figure 4. In such a configuration, a separate line is run for each of the ribs. A common control circuit and a common hydraulic power unit may be used for all the ribs with each rib having a separate associated control valve. This configuration allows to control the drilling direction at multiple location on the drilling assembly.

Figure 4 is a schematic view of a configuration showing three force application members 32a-32c disposed around the non-rotating housing 22 of the bearing assembly 20 of Figures 1-4. The configuration of Figure 4 shows three force application members 32a-32c placed spaced apart around the periphery of the bearing assembly housing 22. The force application members 32a-32c are identical and thus the configuration and operation thereof is described with respect to only the member 32a. The force application member 32a includes a rib member 102a that is radially movable as shown by the arrows 108a. A hydraulically-operated piston 104a in a chamber 106a acts on the rib member 102a to moves the rib member 102a outward to cause it to apply force to the wellbore. The fluid is supplied to the chamber 106a from its

associated power source via a port 108a. As described earlier, each force application member is independently operated to control the amount of the force exerted by such member to the wellbore inside, which allows precisely controlling the drilling direction of the wellbore. The force application members 32b and 32c respectively include pistons 104b and 104c, chambers 106b and 106c and inlet ports 108b and 108c and they move in the directions shown by the arrows 110b and 110c. **Figure 5** is a schematic view of an alternative configuration of the steering members. This configuration differs from the configuration of **Figure 4** in that it does not have the rib members. The pistons 112a-112c directly apply the force on the wellbore walls the pistons are extended outward.

Figure 6 shows a configuration of a drilling assembly 100 utilizing the steering device 30 (see **Figures 1A-1B**) of the present invention in the bearing assembly 20 coupled to a coiled tubing 202. The drilling assembly 100 has the drill bit 50 at the lower end. As described earlier, the bearing assembly 20 above the drill bit 50 carries the steering device 30 having a number of ribs that are independently controlled to exert desired force on the drill bit 50 during drilling of the boreholes. An inclinometer (z-axis) 234 is preferably placed near the drill bit 50 to determine the inclination of the drilling assembly. The mud motor 10 provides the required rotary force to the drill bit 50 as described earlier with reference to **Figures 1A-1B**. A knuckle joint 60 may be provided

between the bearing assembly 20 and the mud motor 10. Depending upon the drilling requirements, the knuckle joint 60 may be omitted or placed at another suitable location in the drilling assembly 100. A number of desired sensors, generally denoted by numerals 232a-232n may be disposed in a motor assembly housing 15 or at any other suitable place in the assembly 100. The sensors 232-232n may include a resistivity sensor, a gamma ray detector, and sensors for determining borehole parameters such as temperature and pressure, and drilling motor parameters such as the fluid flow rate through the drilling motor 10, pressure drop across the drilling motor 10, torque on the drilling motor 10 and speed of the motor 10.

The control circuit 80 may be placed above the power section 12 to control the operation of the steering device 30. A slip ring transducer 221 may also placed in the section 220. The control circuits in the section 220 may be placed in a rotating chamber which rotates with the motor. The drilling assembly 100 may include any number of other devices. It may include navigation devices 222 to provide information about parameters that may be utilized downhole or at the surface to control the drilling operations and/or devices to provide information about the true location of the drill bit 50 and/or the azimuth. Flexible subs, release tools with cable bypass, generally denoted herein by numeral 224, may also be included in the drilling assembly 100. The drilling assembly 100 may also include any number of additional devices known

as the measurement-while-drilling devices or logging-while-drilling devices for determining various borehole and formation parameters, such as the porosity of the formations, density of the formation, and bed boundary information. The electronic circuitry that includes microprocessors, memory devices and other required circuits is preferably placed in the section **230** or in an adjacent section (not shown). A two-way telemetry **240** provides two-way communication of data between the drilling assembly **100** and the surface equipment. Conductors **65** placed along the length of the coiled-tubing may be utilized to provide power to the downhole devices and the two-way data transmission.

The downhole electronics in the section **220** and/or **230** may be provided with various models and programmed instructions for controlling certain functions of the drilling assembly **100** downhole. A desired drilling profile may be stored in the drilling assembly **100**. During drilling, data/signals from the inclinometer **234** and other sensors in the sections **222** and **230** are processed to determine the drilling direction relative to the desired direction. The control device, in response to such information, adjusts the force on force application members **32** to cause the drill bit **50** to drill the wellbore along the desired direction. Thus, the drilling assembly **100** of the present invention can be utilized to drill short-radius and medium radius wellbores relatively accurately and, if desired, automatically.

The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope and the spirit of the invention. It is intended that the following claims be interpreted to embrace all such modifications and changes.